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Science on a Space Elevator

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Introduction

The Space Elevator (SE) represents a major paradigm shift in space access. If the SE's promise of low cost access can be realized, everything becomes economically more feasible to accomplish in space. In this paper we describe in-situ science stations mounted on a science-dedicated space elevator tether.

The concept presented here involves a carbon nanotube ribbon that is constructed by an existing space elevator and then science sensors are stationed along the ribbon at differing altitudes. The finished ribbon can be moved across the earth to the position at which its scientific measurements are to be taken. The ability to station scientific, in-situ instrumentation at different altitudes for round-the-clock observations is a unique capability of the SE.

The environments that the science packages sense range from the troposphere out beyond the magnetopause of the magnetosphere on the solar side of the earth. Therefore, the very end of the SE can sense the solar wind. The measurements at various points along its length include temperature, pressure, density, sampling, chemical analyses, wind speed, turbulence, free oxygen, electromagnetic radiation, cosmic rays, energetic particles and plasmas in the earth's magnetosphere and the solar wind. There exist some altitudes that are difficult to access with aircraft or balloons or rockets and so remain relatively unexplored. The space elevator solves these problems and opens these regions up to in-situ measurements.

Without the need for propulsion, the SE provides a more benign and pristine environment for atmospheric measurements than available with powered aircraft. Moreover, replacing and upgrading instrumentation is expected to be very cost effective with the SE.

Moving and stationing the science SE affords the opportunity to sense multiple regions of the atmosphere. The SE's geosynchronous, orbital motion through the magnetosphere, albeit nominally with Earth's magnetic field, will trace a plane through that region once per day.

Science SE Scenario

A scientific campaign on measuring in-situ properties of the earth from the surface all the way to beyond the magnetopause would represent a "big science" program, bringing together scientists from many different fields to accomplish the mission.

As such the scientists might simply contract for an SE to be constructed. Once a significant SE infrastructure exists, this could be a straightforward process. The baseline in this scenario is for a 20 metric ton capacity ribbon. This SE is 100,000 kilometer long, approximately one meter wide and thinner than a piece of paper [1]. A 200 metric ton capacity SE could erect this ribbon in one lift. In this case, the cost for the cable and the lift could be less than $40,000,000, a small space mission by today's standards.

Alternatively, one might purchase a used space elevator that is nearing its design life. Such an elevator may be showing the signs of wear from climber trips. In its role as a science SE, once the instrumentation is placed along its length, no more climber trips may be planned. Therefore, it could fulfill its mission. One detail is that this means that repair by maintenance climbers will not occur either. It is possible to design science stations along the ribbon that can be picked up by a special climber and then replaced once the climber has passed. However, it is not clear if the mission would require such an arrangement.

Once the SE is constructed or bought, one could move it to its science location or possibly its first science station since it could be moved repeatedly. A ship with the appropriate mass and tether handling apparatus would deliver the SE. Once on station the scientific stations along the tether would begin operating and broadcasting their data to the support ship. The science experiments have begun.

Troposphere Measurements

The troposphere is the lowest component of the atmosphere and the one in which humans experience change as the weather. It stretches from sea level to about 12 kilometers altitude [2]. In the troposphere, temperature decreases monotonically as altitude increases to about -55 degrees Celsius.

The types of in-situ measurements scientists might take along the SE include: temperature, pressure, wind speed and direction, humidity, atmospheric turbulence, degree of ionization and compositional makeup of the air at that altitude. Such point measurements made simultaneously at many places along the SE in the troposphere would represent a type of data set not obtainable presently.

Moreover, the solar illumination at different altitudes and in different conditions over long timescales is important to weather and climatic studies.

Special campaigns are possible with a science SE, especially if moveable. If one expected the SE to survive storm or even hurricane force winds (possibly it could be so designed) then the scientists might even dare to move it into the path of a storm to study the vertical physical and dynamic profile of the storm. Such measurements are quite rare now. (An example is the release of small sensors into tornados for in-situ measurements.) A primary concern would be the safety of the ship or platform during the storm. Another major concern would be the ability of the tether handling apparatus to compensate for the violent ship motion that would be experienced during the storm.

In the far future if weather is manipulated or controlled by mankind, SEs could be the platforms from which chemicals or energy is supplied to the troposphere to exert influence over the weather.

Stratosphere Measurements

The stratosphere stretches from 12 kilometers to nearly 50 kilometers altitude [2]. Temperature increases throughout the stratosphere as altitude increases. At the top of the stratosphere the temperature has increased to about -5 degrees Celsius from -55 degrees Celsius. Most of Earth's ozone is located in the stratosphere. The heating in the stratosphere is caused by the absorption of ultraviolet light by ozone.

In-situ stratosopheric measurements, similar to those in the troposphere, would reveal the state of the ozone. Any chemical threats such as chlorofluorocarbons could be detected directly and quickly, without having to mount a special campaign. Moreover, changes in the state of the stratosphere would be detectable sooner. Presumably the understanding of those changes would be more rapidly achieved as well.

In terms of climate change, the depletion of the ozone layer near the troposphere/stratosphere boundary, the tropopause, is of great importance. Such a depletion could cause the tropopause to rise to higher altitudes. This would represent an increase in the troposphere height and so the "mixing layer" of the atmosphere. The average temperature of the tropopause would then decrease and Earth's surface would cool. It is possible that this is one of the triggering mechanisms of an ice age.

Mesosphere Measurements

The mesosphere starts around 50 kilometers and ends at 80 kilometers [2]. The temperature once again decreases with increasing altitude. In the mesosphere, the temperature falls from -5 to about -100 degrees Celsius.

The highest altitude reached by a research balloon flight was 51.8 kilometers [3]. Thus, the mesosphere is virtually unstudied by balloons. Sounding rockets have taken measurements in this region albeit within the constraints of their operating envelopes. A properly instrumented SE would sense this part of the atmosphere to a degree never before achieved. Breakthroughs could be achieved in our understanding of this part of the atmosphere.

Thermosphere Measurements

The thermosphere extends from 80 kilometers to around 500 kilometers [2]. The temperature increases with altitude from -100 to as much as 1500 degrees Celsius. This heating is from atmospheric gas absorption and bombardment of the molecules by protons and electrons from the sun. Despite the very high temperatures possible in the thermosphere, there is very little heat because the pressure is so low.

The ionosphere is the part of the thermosphere that exists from 100 to 400 kilometers. In this region, the degree of ionization of atmospheric gasses is large. Aurora occur in the thermosphere when electrons from the sun combine with the ionized particles, become neutral and emit light.

Many radio signals are reflected by the ionosphere and thereby propagate great distance around the earth, far beyond the transmitter's horizon. The thermosphere has the same in-situ sensing limitations as the mesosphere, although the ionosphere is probed and studied passively by using radio signals.

An SE, providing in-situ data about the state of the ionosphere will greatly advance our understanding of this region of the atmosphere and its constantly changing state. Communications capabilities will be enhanced with this knowledge.

Because SEs are expected to be set up along or near the equator and aurora are predominantly high latitude phenomena, direct in-situ measurements of auroras may not be made by SE-mounted instrumentation.

Magnetosphere Measurements

The magnetosphere is the environment that the SE experiences along the vast majority of its length. This is from about 500 kilometers to around 100,000 kilometers [4]. Because of the shape of the magnetosphere and its nature of always being in a state of change, the very end of the SE will pass in and out of the magnetosphere daily on the sunward side.

Charged particles flow from the sun (solar wind) and along solar magnetic lines into the system at about 300 kilometers/second. These particles encounter and pass through the bow shock of the magnetosphere on the sunward side of the earth. Most particles are deflected around the magnetosphere along the magnetosheath. Hence Earth is protected from most of the particle radiation from the solar wind. Some particles do cross magnetic field lines and enter the magnetosphere. Also, there are two points neutral magnetic field points, polar cusps) along the boundary between the magnetosheath and the magnetosphere called the magnetopause. At these two points, particles can enter the magnetosphere without crossing magnetic field lines. Eventually, particles flow out of the system, away from the sun, down the magnetotail.

The solar wind is variable. The state of the magnetosphere is always changing because of the solar wind variability and the fact that Earth's magnetic field rotates with the earth, always being dragged around and through the magnetosphere, which does not rotate. The magnetic field lines continually interact with the charges particles both modifying locally the charged particle states and experiencing locally the effect of the charged particles upon the magnetic field. Within the magnetosphere exist regions of intense charged particle trapping (the van Allen radiation belts). The boundaries of the system such as the bow shock and magnetopause are always changing position and physical state as the solar wind changes. Periods of high solar activity cause storms of charged particles to impact the magnetosphere, compressing it, increasing the local magnetic field strength, forcing many more particles into the magnetosphere and changing the state of the system dramatically. Over time the system sheds the particles and returns to a non-storm level of variability.

In the magnetosphere, as well as the thermosphere, some different measurements need to be taken to understand the environment. The magnetosphere is a very hard vacuum. However, it is populated with charged particles (and in some regions neutral particles exist) that interact with Earth's magnetic field. Therefore, the instrumentation on the SE sensing platforms must measure the particle composition as a function of energy and direction (pitch angle distribution). The charge state of these ions must be measured as well. The magnetic and electric fields must be measured, both the magnitude and direction of each.

Currently, satellites measurement the state of the magnetosphere at one point, at one time. As they orbit they make measurements but their speed carries them through the magnetosphere. The SE instrumentation will be measuring the magnetosphere in a line straight out from Earth, that is rotating along with the earth. It too will be moving through the magnetosphere but its larger number of measurements and the placement of those measurements, will shed new light on the physics of the magnetosphere. In fact, the very end of a 100,000 kilometer SE will exit the magnetosphere on the sunward side and afford measurements to be made in the magnetosheath and possibly the bow shock and solar wind as well.

Conclusions

Science platform mounted on an SE dedicated to a science mission could revolutionize in-situ measurement of atmospheric and magnetospheric research. No other technology can provide the same siting opportunities for scientific instrumentation.

Moreover, sensing in space can be accomplished much more inexpensively than with current satellite missions. Some of our current satellites are in excess of $1 billion. Once an SE infrastructure has been established, an entire science-dedicated SE campaign could cost less and provide many orders of magnitude more data than current space missions.

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